PARAMETROS DEL IMPACTO EN RELACION CON LA MAGULLADURA Y CON OTRAS PROPIEDADES DE LOS FRUTOS

Ruiz Altisent M.
Dept. de Ingeniería Rural

ETSIA, Universidad Politécnica de Madrid

RESUMEN

Durante los últimos cinco años se ha estudiado la respuesta al impacto en frutos, especialmente manzanas y de peras.

Utilizando un dispositivo de ensayo de impactos así como caída libre de manzanas instrumentadas, ha sido posible establecer un conjunto de resultados, relativos a los parámetros que mejor caracterizan la respuesta al impacto de estos materiales, y a su correlación con la magulladura, la variedad y la madurez de los frutos.

La magulladura está relacionada directamente con la energía de impacto aplicada (altura de caída), para una variedad determinada, y a un determinado nivel de madurez. Los parámetros más importantes son deformación máxima (DM), deformación permanente (DP), impulso máximo (IM), fuerza máxima en el impacto (FM), valor máximo de la pendiente fuerza/tiempo (F/T)· y duración del impacto (T). FM, F/D y F/T son los que mejor describen las diferencias de madurez, variando éstos sin embargo en las diferentes especies de frutos.

IMPACT PARAMETERS IN RELATION TO BRUISING AND OTHER FRUIT PROPERTIES.

Margarita Ruiz, Professor

Dept. Ingeniería Rural
ETSIA. Univ. Politécnica de Madrid. SPAIN

ABSTRACT.- Impact response in fruits, primarily apples and pears (Pomaceae fruits), has been studied during the last five years. Using a laboratory impact testing device and also free-fall tests of instrumented apples, a significant body of results has been established, relative to the parameters which best characterize the impact response of these materials, and to their correlation with bruise damage, variety and ripeness level of the fruits.

Bruise damage, measured as the size and/or volume of the affected fruit tissue is related primarily to applied energy (i.e. mainly drop height) for a given variety at a given ripeness stage. The relevant impact response parameters are maximun deformation (DM), permanent deformation (DP), maximun impulse (IM), maximun impact force (FM), maximum value of the force/time slope during impact (F/T) and impact time (T). The effect of ripeness differences was also studied in selected varieties of pears, being the most relevant parameters: maximun force (FM) and F/T slope.

INTRODUCTION

Harvesting and handling operations subject fruits to impact situations which often cause bruising. Bruising appears as a result of impacts and compressions of the fruits on other fruits, parts of the trees, containers, etc. and on any uncushioned surfaces.

As has been stated, severity of damage is primarily related to height of fall, initial velocity, number of impacts, type of impact surface and size and maturity of the fruit. Researchers have developed theoretical applied models to analyze impact problems (Horsfield et al., 1972; Rumsey and Fridley, 1977; Chen et al. 1984). First, the elastic contact model (Hertz model, developed further by Shigley) was applied, and a good explanation of the stresses and strains which develop in the fruit as a consequence of static or also impact contact can be obtained, for contact duration times of less than one-quarter of the relaxation time; an impact on fruits lasts below 10 miliseconds. The viscoelastic effect on stresses and strains developed during impact has been studied (Rumsey and Fridley, 1977; Jarimopas, 1984), showing that large strains appear for higher-energy impacts and softer materials, so that the elastic solution is not appropriate in these cases. Also, fruits change gradually from a predominantly elastic stage to a viscous-plastic during ripening.

Instrumental measurement of the impact response is today available (Chen et al 1985, 1986; Brusewitz and Bartsch, 1989, Lichtensteiger et al. 1988).

During the last decade, our research team has been studying the physical properties of fruits and vegetables, in relation to resistance to mechanical damage and to texture (i.e. quality of the product when consumed). As a result of a Cooperative project with the Univ. of California, it was possible to study impact response of the fruits, after developing a similar impact testing instrumentation, and in the last years, some significant results were obtained in various aspects:

1) Establishment of the parameters which characterize the response of a fruit to an impact applied by a free-falling instrumented impacter, in selected varieties of apples and pears.

2) Prediction of the degree of bruising of Golden Delicious apples falling on different surfaces by multiple regression models based on a) impact parameters and b) Fourier-transform -

coefficients of the impact accelera-- ration curves.

3) Development of a procedure where impacts of small energy, no-damaging to the fruits, can be used to predict the ripeness level of many fruits.

4') Some characteristics which define the bruised tissue in these fruits - were established, as well as:

5) Procedures for observation and - evaluation of bruises, using some -- dying chemicals.

IMPACT PARAMETERS AND DAMAGE

The impact testing device used in our tests has been described previously - (Chen et al, 1985; García et al, 1988).

The approach which was made on the - "damage vs. impact" problem was in - this case a very empyrical one, --- collecting a high number of data, with variation of all the characteristics and parameters which were thought to potentially influence impact response and bruise appearance. Consequ ently, different varieties of two species of fruits were studied, in varying post-harvest ripeness stages, for varying impact energies (García et al, 1988). All the data were then introduced in a particular analysis procedure (the correspondence factorial analysis), - appropriate to study the variation of variables and parameters from which - no previous relationships are --- established or known. The results of this analysis, studied separately for the different fruit varieties, were then interpreted by means of spatial representations of the variable values.

Many parameters can be obtained from the acceleration curves measured by means of the impact testing device. In the different phases of these --- projects, several studies have been - carried out to determine relations - between each of those parameters and the characteristics of the fruits, - like varietal differences, ripeness - level and bruising resistance. Bruise size appears usually related directly to impact energy with no large --- influence of other parameters when - using equal products at equal condi-- tions of maturity (Figs. 1a and 1b). As has been stated, the application of the elastic contact model yields - some parameters which can be used to know the stresses and strains which - are created in the fruit tissue during impact, and compare them with the - size, position and characteristics of the bruises which appear in the --- different fruits. This model was used and the parameters obtained by this - way were introduced in the described analysis.

After these studies, we were able to - conclude that the relevant parameters describing the response of the tested fruits to impact (Table 1) can be -- classified in three groups according to their correlated variation in -- relation to impact energy and to the resulting bruise size. The first -- group of parameters are those most - closely related to impact energy, and therefore to size of bruise:

maximun deformation (DM),
permanent deformation,
maximun impulse;

The second or intermediate group is made up by those parameters which -- correlate to energy level and to -- ripeness level at the same time, - therefore influencing bruise size in an interaction:

maximun impact force (FM),
maximun value of the force/time slope (F/T=DAM),
rebound velocity.

Finally, the third group is made up - by those parameters whose values are largely independent from impact --- energy (for impacts of 2 to 20 cm of height of free-fall of a 50 gram - sphere) and closely related to texture (ripeness level) of these fruits:

total impact duration (T) (= contact time),
time to maximun force,
force/deformation slope (F/D).

These results are largely coincident with the ones obtained by other -- researchers. The maximun value of the force/time slope (F/T) (Delwiche, -- 1987; Chen and Yazdani, 1989; Brusewitz and Bartsch, 1989) has been recognized as one of the relevant parameters - causing bruising, together with: both F (maximun force) and T (contact time), and absorbed energy (EAB) and its - component maximun deformation, DM.

Elastic rebound of the impacter was - calculated from its final velocity - (=rebound velocity). It was shown that the percentage of elastic rebound - energy decreases as drop height and - ripeness level increase, from about - a 40% to less than 10%. This shows - that the behaviour of the fruits is - elastic only to a degree, becoming - more and more plastic as ripeness and/ or impact energy increase.

The impact parameters were also - analyzed in relation to the degree of bruise (Table 2), and in a different group of tests. (Chen and Yazdani, - 1989). This study led to conclusions about the prediction of the degree of fruit damage from measured and calcu- lated parameters. In this case, Golden Delicious apples were used, and they were tested by dropping them onto - hard and padded surfaces, from ---

different heights. A fruit holder was attached to half-apples, attaching the accelerometer at the center of this holder.

The result of a stepwise regression analysis, using the bruise volume as the dependent variable and all the other measured and calculated impact parameters as independent variables, indicated that the six most important parameters for predicting bruise were DAM (the maximun value of the time rate change of acceleration during an impact, =F/T), DM (maximun deformation), EAB (absorbed energy), FM (maximun force), T (impact time) and PT (padding thickness).

Golden Delicious apples should not be dropped on hard surfaces. It was found that even a two-cm drop on a rigid surface will result in a small bruise. Proper paddings should be used on all impacting surfaces. A firm padding (Rubatex or similar materials) 3 mm thick should be used for drop heights ranging from 1 to 8 cm; 5 mm thick for drops of 8 to 20 cm, and 7 mm thick for drops of 20 to 35 cm. (Chen and Yazdani, 1989).

IMPACT PARAMETERS AND RIPENESS LEVEL

Impacts of 4 cm height of free-fall of a 50-gram spherical impacter were applied to Limonera pear (Bartlett type) during a 12-week period of ripening in cold-storage and shorter periods of ambient-temperature storage. These fruits ranged from a very hard to a very soft, non commercial stage, and this small impact did not produce a visible bruise in the fruits. Objective ripeness determinations were used: days of storage and/or ripening penetrometer reading (Magness-Taylor in the Instron machine, MT) and also a newly developed one, based on pure shearing of cylindrical specimens, FC. These correlated closely using multiple linear regression models with impact parameters, including from three to fifteen of them as independent variables (Fig.3). The possibility of developing this principle for fruit quality monitoring equipment is being studied. (Ruiz et al., 1989).

BRUISE CHARACTERISTICS AND DEVELOPMENT

Different varieties and ripeness stages of the fruits show different bruise sizes, as has been shown, and the bruises may also differ in shape and internal structure. One important conclusion is that the "bruising reaction", involving softening of the tissue and discoloration can be produced with or without cell-wall rupture. Rupture of cell walls is caused when the cells in the tissue are not capable of absorbing the applied deformation; but, according to our observations, applying pressure on the cells, without attaining rupture of the walls, also initiates the softening and browning reactions. The observed alterations include citoplasm disorganizations, walls softening and destruction of middle-lamellae. The whole of the stressed tissue is affected by the bruising reactions, but not the non-stressed tissue, even during long periods of cold-storage. The differences observed in the tissue structures between most varieties of apples and pears (cell size and shapes, in epidermis, hypodermis and parenchima, as well as intercellular spaces) lead to an explanation of the different bruise sizes, shapes and structures observed in the varieties tested. (Ruiz et al. 1989) (Figs. 1 and 2).

COLORIMETRIC TECHNIQUES TO REVEAL THE BRUISES

Based on the well-known poliphenols oxidations that take place in the bruised tissues, some reactives can be used to reveal the activity of the enzimes that actuate in these reactions. The reactive Cathecol is very convenient for this purpose: it is simple to prepare and to use, inexpensive and fast. It can be used by dipping whole fruits, and by direct application on bruises or dipping of fruit slices. It reveals, blackening them out, the bruised areas without affecting the surrounding fruit tissue. (Ruiz et al. 1989).

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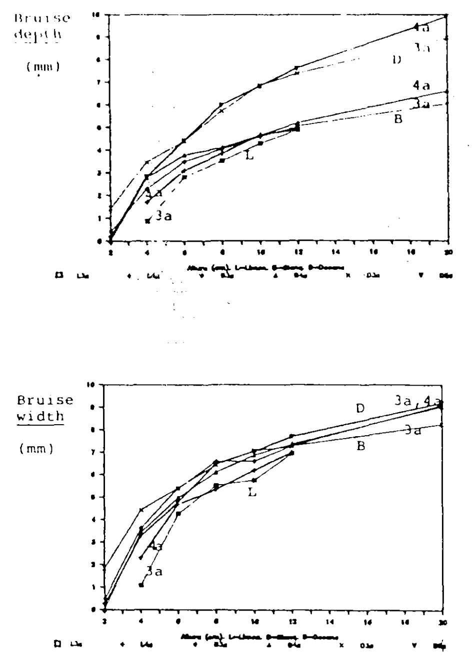

Figure 1 a. Depth and width of bruise in relation to impact severity (2 to 20 cm drops);pears, 6th and 8th weeks of cold storage,0 days ripening. L: "Limonera" B:"Blanquilla D: "Decana". 3a: 6th week ; 4a: 8th week.

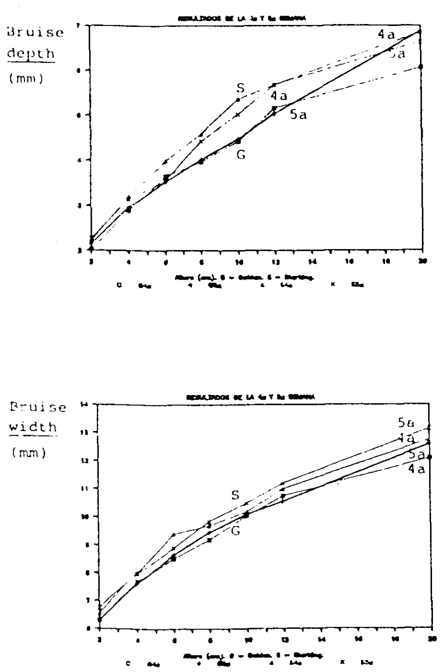

Figure 1 b. Depth and width of bruise in relation to impact severity (2 to 20 cm drops): apples, 8th and 10th weeks of cold storage, 0 days ripening. G:"Golden Delicious"; S: "Starking". 4a: 8th week; 5a: 10th week.

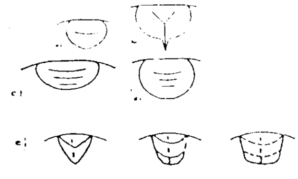

Fig. 2. Types of bruises and fractures or fissures observed in the varieties of apples and pears tested. (12 cm drops). a) Limonera pear; b) Decana pear; c) Golden and Starking apples; d) Blanquilla pear; e) Blanquilla pear: 1: hard fruits 2) ripe fruits, 3) soft fruits.

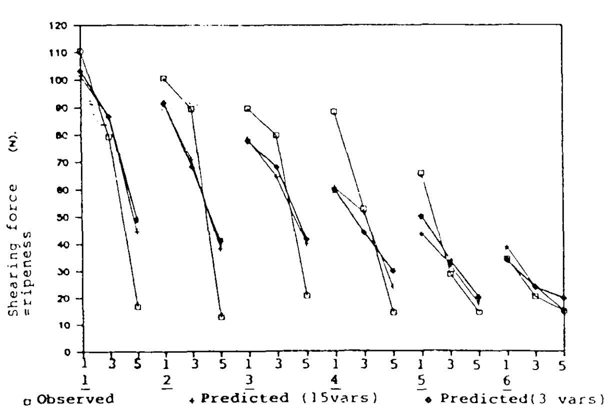

Fig.3. Observed and predicted values (by non-destructive impact response) for ripeness in "Limonera" pear. For 6 2-week testing periods, 1st, 3rd and 5th days of ripening in 18ºC room. Fruits were considered non-commercial for ripeness values below 60 N of shearing resistance. (Ruiz et al. 1989).

Table 1.- Summary of impact parameters studied.

Name of parameter	S.I. Units	Symbol
Maximum deformation	mm	DM
Permanent deformation	mm	DP
Critical depth (maximum shear stress location Hertz model)	mm	PC
Maximum mechanical impulse	N x s	IM
Maximum bruise depth	mm	PM
Maximum bruise width	mm	AM
Percentage of rebound energy	%	%E
Maximum impact force	N	FM
Optimum slope force/time	N/s	F/T
Calculated coefficient	N^2/s	IF x F/T
Rebound velocity	m/s	VF
Total impact duration	ms	T
Final impact duration	ms	TF
Time to maximum force	ms	TM
Increment TT-TF	ms	IT
Optimum slope force/deformation	N/m	FD
Aparent dynamic modulus of elasticity	Pa	ME
Maximum shear stress	Pa	EC

Table 2.- Values of most significant correlation coefficients for selected parameters.

Parameter	Correlated with	Correlation coefficient r / no. obs.		Variety and storage conditions
Bruise width (A.M)	Drop height	0,744	(n = 300)	Limonera Pear, cold storage
Bruise width (A.M)	Drop height	0,685	(n = 150)	Limonera Pear, ripening room, 3rd week test
Bruise depth (P.M)	Drop height	0,733	(n = 300)	Limonera Pear, cold storage
Bruise depth (P.M)	Drop height	0,678	(n = 150)	Limonera Pear, ripening room, 3rd week test
Testing date	Maximum Magness Taylor force	- 0,78	(n = 60)	Limonera Pear cold storage
Testing date	Maximum Magness Taylor force	- 0,702	(n = 30)	Limonera Pear ripening storage
Testing date	Optimum slope Force/ deformation	- 0,865	(n = 60)	Limonera Pear cold storage
Testing date	Optimum slope Force/ deformation	- 0,723	(n = 30)	Limonera Pear ripening storage
Bruise width (A.M)	Drop height	0,895	(n = 1050)	Golden Delicious apple, all tests
Bruise depth (P.M)	Drop height	0,911	(n = 1050)	Golden Delicious apple, all tests